



# Taking on the Stars

## Teller's Contributions to Plasma and Space Physics

*January 15, 2008, marks the 100th anniversary of Edward Teller's birth. This highlight is the fifth in a series of 10 honoring his life and contributions to science.*

**I**N *Memoirs*, Edward Teller recalls that the founding of Lawrence Livermore brought together physicists from two research areas: thermonuclear weapons design and controlled fusion. The broad set of physical processes studied in these fields also lies at the heart of astrophysics. Fusion reactions power the stars, and the temperatures and pressures occurring in stellar environments reflect those in an exploding nuclear device. As a result, insights made in one field often advance research in another.

In the 1930s, many physicists, including Teller, applied the new mathematical tools of quantum mechanics to study the physical processes occurring in stars—how they form, evolve, and die and how they create new elements. While at George Washington University, Teller and George Gamow developed calculations for determining the rate of energy produced in thermonuclear fusion reactions in stars. The Gamow–Teller estimates, which they published in 1938 in *Physical Review Letters*, proved important to many research areas, including studies of nucleosynthesis—the stellar processes that lead to new elements.

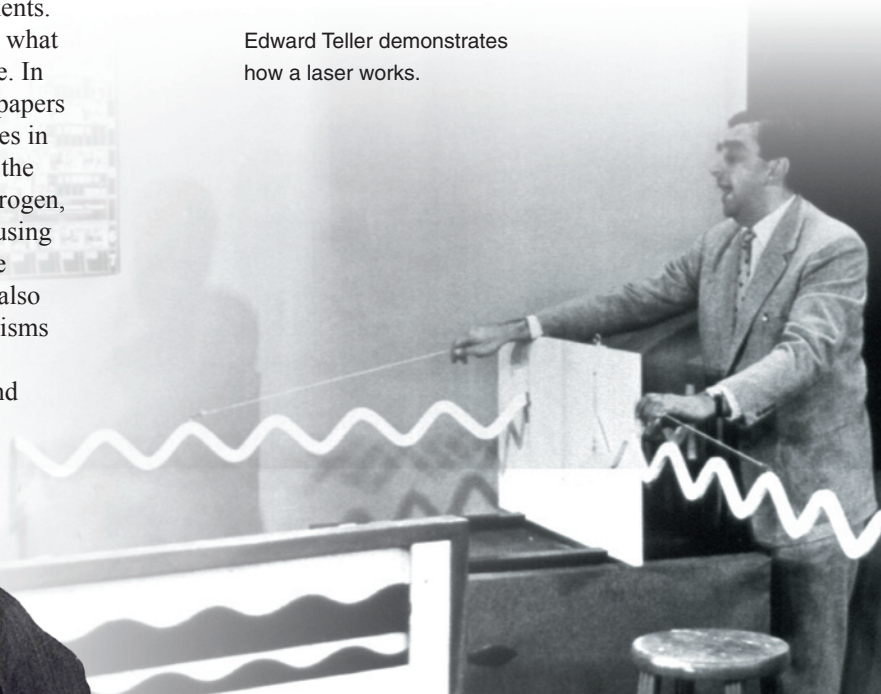
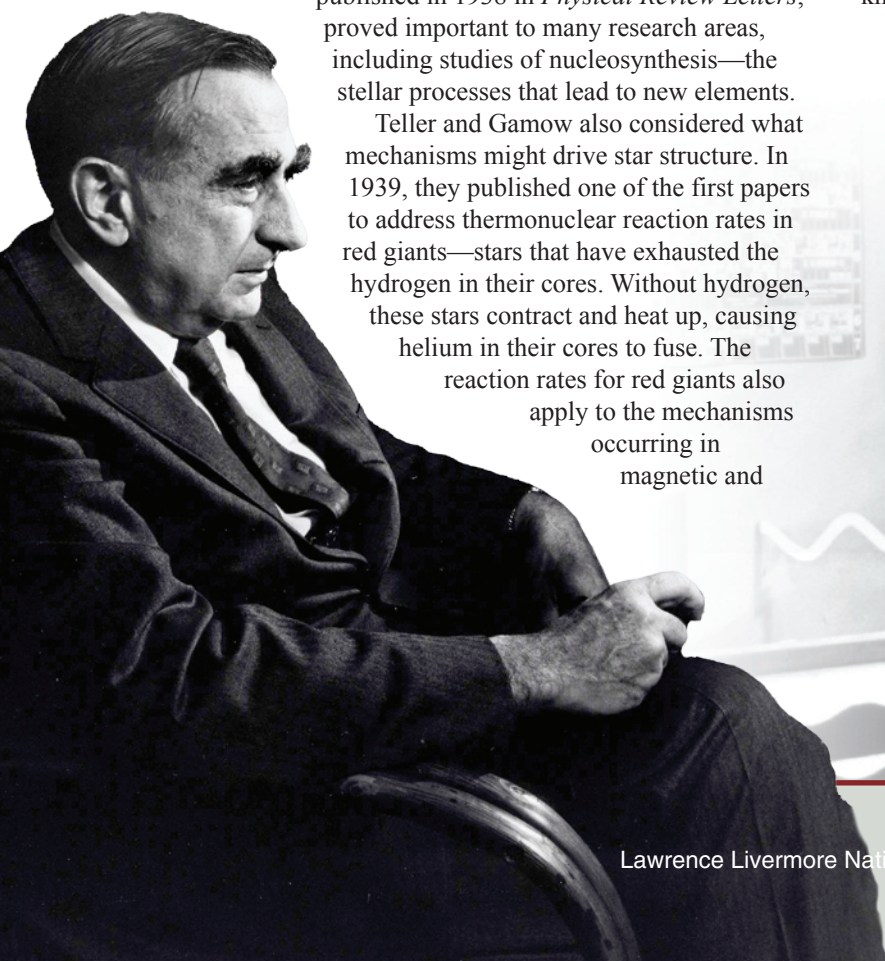
Teller and Gamow also considered what mechanisms might drive star structure. In 1939, they published one of the first papers to address thermonuclear reaction rates in red giants—stars that have exhausted the hydrogen in their cores. Without hydrogen, these stars contract and heat up, causing helium in their cores to fuse. The reaction rates for red giants also apply to the mechanisms occurring in magnetic and

laser fusion systems and in thermonuclear weapons. Although Gamow and Teller's preliminary hypothesis for red giants proved wrong, their work stimulated other ideas on star formation.

Teller's work with Gamow on basic nuclear physics also had a profound effect in astrophysics. The Gamow–Teller transitions, originally proposed as an addition to Enrico Fermi's theory of beta decay, helped researchers understand the proton–proton chain that powers the Sun.

Prior to World War II, Hans Bethe explained how fusion reactions create lightweight elements up to iron, which has 26 protons in its nucleus. Research indicated, however, that this type of nucleosynthesis did not apply to heavier elements. Astrophysics research declined during the war, as scientists turned their attention to national security missions. When the war ended, many renewed their studies of nucleosynthesis. In a 1949 paper published in *Physical Review*, Teller and Maria Mayer suggested that a fission process involving a neutron-rich nuclear fluid forms these heavy elements. Their hypothesis was a step toward today's theories explaining the slow and rapid neutron-capture mechanisms known as the s- and r-processes.

Edward Teller demonstrates how a laser works.



At a star's inner core, extreme gravitational forces squeeze matter to high densities and temperatures. Understanding the physical processes occurring inside stars requires basic research on the physics of dense plasmas—another topic that captured Teller's interest. He and David Inglis explored how the conditions in a plasma might affect spectral data recorded in plasma experiments. In their 1939 paper published in *Astrophysical Journal*, they proposed that the bound electrons in a dense plasma—particularly those in orbits farthest from the nucleus—weakened their bonds. This change, which is caused by the electric fields from nearby ions and electrons, broadens the spectral lines of the outermost orbits. The Teller–Inglis hypothesis proved correct. Broadened lines appear in spectra of high-density plasmas in stars and in condensed-matter experiments.

At Los Alamos, Teller continued to study dense plasmas. Working with Richard Feynman and Nicholas Metropolis, he developed equations of state for elements at high pressures and various temperatures. Researchers in many disciplines, including astrophysics, continue to use the data tables in their much-cited paper, which was published in *Physical Review* in 1949.

In 1958, researchers discovered the existence of the Van Allen Belts—energetic charged particles trapped in orbit around Earth by the planet's magnetic field. Understanding the mechanisms holding these radiation belts in place is important to studies of Earth's near-space environment and to research on magnetic fusion machines designed to contain plasmas for long periods. In 1959, Teller and Theodore Northrop proposed that approximate conservation laws would force the motion of charges in Earth's magnetic field to be smooth and stable, thus leading to the stability of the Van Allen Belts. Later research indicated that chaotic motions are indeed possible. The role of the proposed conservation laws in these orbits is still under debate.



Teller tours the National Ignition Facility (NIF) with (left) Valerie Roberts, construction manager, and Ed Moses, associate director for NIF Programs.

Another puzzle that captured Teller's attention concerned the origin of cosmic rays, energetic particles that impinge on Earth's atmosphere and the interstellar medium. In 1949, he and Robert Richtmyer proposed a model for cosmic-ray generation near the Sun. Other researchers, including Fermi, suggested coherent mechanisms for cosmic-ray acceleration over interstellar and galactic scales. All of these theories relied on the equations developed by Teller and Frederic de Hoffmann to explain shock-wave behaviors in magnetized plasmas.

Given Teller's interest in plasma physics and the nature of stars, it is no surprise that astrophysics found a home at Livermore. Some of the first shock-physics experiments at the National Ignition Facility will examine these extreme environments. (See the highlights beginning on pp. 20 and 22.) Results from those experiments will also benefit the Laboratory's national security missions. As Teller says in *Memoirs*, "Livermore has emphasized astrophysics and other branches of pure science in the recognition that great progress in applications cannot be made if science itself is neglected."

—Ann Parker

**Key Words:** astrophysics, controlled fusion, Edward Teller, thermonuclear weapons.

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